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Research Article

Integration Pathways of AI-Generated Tools and Cultivation of Instructional Innovation Competencies in Pre-Service Teacher Preparation: A Literature Review and Practical Implications

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Abstract

With the rapid iteration of generative artificial intelligence technology, AI-generated tools have become a core variable reshaping the education ecosystem and have also placed new demands on the competency structure of pre-service teachers. This study, based on domestic and international literature on the application of AI-generated tools in pre-service teacher education, employs an integrative literature review approach to examine existing research findings from four aspects: the connotation of core concepts, the current state of cognitive application, curriculum integration paths, and competency development dimensions. Given the rapidly evolving nature of the topic and the limited pool of empirical studies available, an integrative review design was chosen over a full systematic review to allow for critical synthesis of both empirical and conceptual works.The study finds that the academic community has formed a hierarchical conceptual system of AI literacy and AI competency, constructing three typical integration paths: curriculum embedding, workshop intervention, and practical penetration. However, pre-service teachers generally suffer from low levels of AI application, a disconnect between theoretical understanding and teaching practice, and insufficient ethical critical thinking. Based on these findings, this paper proposes practical strategies such as a hierarchical and progressive competency development system and a closed-loop “theory-practice-reflection” training model.

Keywords

Generative artificial intelligence, Pre-service teacher training, AI literacy, Teaching innovation ability, Integration pathway

1. Introduction

The explosive adoption of generative artificial intelligence is accelerating the transformation of global education from a digital to an intelligent phase. AI applications such as ChatGPT and multimodal content generation tools are not only changing how students learn but also reshaping the working logic of teachers. As the core force of future basic education, pre-service teachers' ability to master AI tools and conduct teaching innovation directly determines the quality and direction of future intelligent education.

Currently, the integration of AI in pre-service teacher education is still in the exploratory stage, and there are many practical difficulties in practice: First, the integration is fragmented, with most institutions only involving AI content in scattered lectures or single courses, lacking a systematic capacity building system; second, it is treated as a tool, with many training programs equating AI education with software operation training, neglecting core competencies such as critical thinking and ethical judgment; third, it is disconnected from practice, with pre-service teachers mostly using AI in their personal learning, but finding it difficult to transform it into innovative applications in teaching scenarios.

This study, through a systematic review of relevant domestic and international core literature, focuses on two core questions: First, what is the connotation of pre-service teachers' AI literacy and teaching innovation ability? What typical integration paths and training models have existing studies revealed? Second, what common dilemmas exist in current practice? What practical optimization strategies can be developed for cultivating teaching innovation ability?

2. Research Methods

2.1. Search Strategy

Four databases were searched: Web of Science Core Collection, Scopus, ERIC (EBSCO), and CNKI (China National Knowledge Infrastructure). The search covered publications from January 2018 to December 2025. The search strings combined three concept blocks using Boolean operators: ("generative AI" OR "AI-generated tools" OR "ChatGPT" OR "artificial intelligence in education") AND ("pre-service teacher*" OR "teacher education" OR "teacher training" OR "student teachers") AND ("AI literacy" OR "AI competency" OR "instructional innovation" OR "teaching innovation" OR "TPACK"). For the CNKI database, equivalent Chinese terms were used.

2.2. Inclusion and Exclusion Criteria

Studies were included if they: (a) were peer-reviewed journal articles or authoritative policy documents; (b) focused on pre-service teachers or teacher education programs; (c) addressed AI

literacy, AI competency, or instructional innovation with AI tools; and (d) were published in English or Chinese between 2018 and 2025. Studies were excluded if they: (a) targeted only in-service K-12 teachers without a teacher-education component;(b)were conference abstracts, editorials, or non-peer-reviewed materials; or(c) discussed AI technology without an educational application.

2.3. Quality Appraisal and Data Synthesis

Each included study was appraised using a standardized quality checklist covering research design, sample description, measurement validity, and transparency of reporting. Data were extracted according to a predefined form including author, year, country, participants, methodology, AI application context, key findings, and AI competency dimension addressed. A thematic synthesis approach was then applied to identify four cross-cutting themes: (1) core concepts and theoretical frameworks; (2) current understanding and application status; (3) integrated practical pathways; and (4) competency development dimensions.

3. Research Results

3.1. Core Concepts and Theoretical Framework: Deconstructing the Connotation of AI Literacy and Teaching Innovation Ability

3.1.1. Layered Definition of AI Literacy and AI Competency

AI literacy and AI competency are two core concepts in the field of pre-service teacher AI education. They are related but also have clear hierarchical differences. Hsu (2026) clearly points out that AI literacy is a shared knowledge base for individuals to understand the operating logic of AI systems, evaluate the quality of AI output, and consider the ethics of AI applications. Specifically, it includes three core dimensions: first, the understanding of the basic principles and operating mechanisms of AI; second, the ability to critically evaluate the content of AI output; and third, the ethical and socio-technical awareness of AI applications.

AI competency, on the other hand, refer to the contextualized application of AI literacy in professional scenarios. Specifically, it refers to teachers' practical ability to effectively, critically, and ethically use AI tools in their professional work such as teaching, assessment, and classroom management, emphasizing the deep integration of technology, teaching methods, and subject content.

This definition resonates with the classic TPACK (Technology-Teaching-Content Knowledge) framework. Gulen&Kucuk (2026) further propose an AI-TPACK extension framework, pointing out that teachers' knowledge structure in the AI era needs to integrate the ability to select, evaluate, and integrate AI tools at the intersection of traditional technical knowledge, teaching methodology knowledge, and subject knowledge, achieving a leap from "knowing how to use technology" to "effectively using technology to empower teaching." Furthermore, regarding the influencing factors of

AI literacy, related research has confirmed that pre-service teachers' perception of AI applications, their overall attitude towards AI, and their own machine learning knowledge reserves are the core antecedent variables affecting their AI literacy level, providing a logical starting point for the design of training pathways (Laru et al., 2025).

3.1.2. Reference to Internationally Authoritative Capability Frameworks

Currently, two influential AI competency frameworks have emerged internationally, providing standardized references for pre-service teacher training. The first is the UNESCO AI Competency Framework for Teachers, which centers on a "human-centered approach" and divides teachers' AI competency into three progressive levels: introductory learning, in-depth application, and innovation, based on five dimensions: humanistic thinking, AI ethics, AI fundamentals and applications, AI pedagogy, and AI professional development. This framework clarifies a tiered development path for teachers' AI competency. The second is the AI Literacy Framework jointly proposed by the European Union and the OECD. This framework, starting from four interactive domains—participation, creation, management, and design—defines the core competencies learners should possess when interacting with AI, emphasizing human agency and initiative, and opposing technological determinism (Hsu, 2026).

3.1.3. The Connotation of Teaching Innovation Ability in the AI Context

The widespread adoption of AI-generated tools has redefined the connotation and boundaries of teachers' innovative teaching capabilities. Traditional teaching innovation often focuses on localized improvements to teaching methods, while the innovative teaching capability in the AI era is the ability of teachers to leverage AI tools to break through the limitations of traditional teaching and achieve creative changes in areas such as instructional design, assessment methods, and teacher-student interaction. Meegan and Young (2025) point out that this innovative capability is built upon teachers' AI self-efficacy—only when teachers believe they can master AI tools and judge the value of AI output will they dare to try innovative teaching models.

3.2. Real-world scenario: Current status of pre-service teachers' understanding and application of AI-generated tools

3.2.1. Attitude: Overall optimistic but full of contradictions

Existing research shows that pre-service teachers worldwide generally hold a cautiously optimistic attitude towards AI-generated tools, but there is a widespread cognitive contradiction. A study by Yadav et al. (2025) of pre-service teachers at universities in the Midwestern United States showed that 82.3% of respondents believed that AI tools could improve some aspects of teaching, and 70.6% believed that AI would trigger innovation in the field of education.

However, concerns and doubts are also widespread. A survey of 240 pre-service teachers in

Latvia by Kalniņa et al. (2024) showed that only 43% of respondents had used AI tools in their studies, 37% had never used them, and 20% were unsure whether they had even used AI. 66% of respondents believed that AI would encourage students' laziness and reduce their willingness to think independently, and 59% of respondents worried that AI would exacerbate academic misconduct.

3.2.2. Application: More individual learning, less teaching application

From an application perspective, pre-service teachers' use of AI tools is mostly concentrated on personal learning, with a serious lack of transformation into teaching practice. Kalniņa et al. (2024) found that the most frequently used AI tools by pre-service teachers are translation and grammar correction tools, followed by information retrieval tools; while the proportion of AI used in teaching scenarios such as instructional design and assessment design is extremely low. Although 61% of respondents agreed that AI can help differentiated teaching and support students with special needs, 55% of respondents said they had never tried AI-assisted inclusive teaching in their teaching practice, forming a clear gap of "theoretical recognition but practical absence".

The research by Estaiteyeh and McQuirter (2024) also confirms this: in teacher education workshops in early 2023, most pre-service teachers and teacher educators only regarded AI as a tool for students to cheat, and had not yet realized its potential for teaching innovation.

3.2.3. Gap: Weak Critical and Ethical Awareness

The core of AI literacy—critical evaluation ability and ethical awareness—is a common weakness among current pre-service teachers. Yadav et al. (2025), through a case study of instructional design, found that pre-service teachers initially tended to blindly trust the content generated by AI when using ChatGPT to generate lesson plans; only respondents with solid subject teaching knowledge were able to identify factual errors, logical flaws, and issues of pedagogical suitability in the AI output. Most pre-service teachers lack the awareness to proactively verify AI content and screen for algorithmic biases, and rarely consider ethical issues such as data privacy and intellectual property rights.

The study by Gulen and Kucuk (2026) also showed that although pre-service teachers scored at a moderate level in the AI ethics dimension before intervention, their scores were mostly generalized moral cognitions, lacking the ability to make specific ethical judgments in educational scenarios.

3.3. Multiple Approaches: Integrating AI-Generated Tools into the Practice of Pre-Service Teacher Training

Existing research has explored three effective integration paths, which correspond to three different training objectives: systemic capability enhancement, short-term cognitive breakthrough, and practical ability transformation, forming a complementary training system.

3.3.1. Curriculum-based embedding: The core vehicle for systematic competency

enhancement

Systematically embedding AI content into teacher education courses is the most fundamental path to improving pre-service teachers' AI literacy and teaching innovation capabilities. The quasi-experimental study by Gulen and Kucuk (2026), involving a sample of 50 pre-service teachers (41 female, 9 male) enrolled in a compulsory "Instructional Technology" course, validated the effectiveness of this approach. Using a one-group pretest–posttest design with the Artificial Intelligence Literacy Scale and the Digital Material Design Competency Scale as outcome measures, the researchers fully integrated AI content into the 14-week progressive curriculum—from an introduction to basic AI concepts and ethical norms, to prompt engineering and AI-assisted content creation, then to digital material design, AI-assisted lesson preparation, and AI-supported differentiated teaching, culminating in AI-integrated lesson plan design and presentation. After one semester, paired-sample t-tests revealed significant improvements in total AI literacy (d=1.57, large effect) and digital material design competency (d=1.73, large effect).

Hsu (2026) also proposed that AI courses should include three types of progressive teaching activities: establishing basic cognition through lectures, developing assessment and ethical competence through critical inquiry, and honing teaching application and innovation capabilities through collaborative design.

3.3.2. Workshops and Scenario-Based Interventions: Effective Forms of Short-Term Immersive Breakthroughs

For goals such as cognitive development and breakthroughs in specific skills, short-term workshops and scenario-based interventions are efficient and flexible training methods. The three-part workshop series conducted by Estaiteyeh and McQuirter (2024) at Brock University is highly representative: the researchers designed differentiated discussion topics for three different audiences—full-time teacher educators, secondary school subject lecturers, and part-time lecturers—focusing on academic integrity, intellectual property, and research ethics for full-time professors, and on teaching applications, assessment reform, and curriculum adjustments for subject lecturers. The results showed that the workshops not only rapidly improved participants' AI awareness but also spurred subsequent curriculum reform practices, driving the updating of AI content in digital technology and language arts courses.

Meegan and Young (2025) explored an intervention model that combines contextual learning (SBL) with AI: researchers use AI tools to generate real teaching dilemma scenarios, guide pre-service teachers to analyze problems from multiple perspectives, propose solutions, and continuously optimize solutions through dialogue with AI.

3.3.3. Integration into Practical Scenarios: Skills Transformation in Educational Internships

The ultimate goal of pre-service teacher training is educational internship, and the integration of AI tools must also extend to the internship field to achieve the transformation from “learning” to “using”. Estaiteyeh and McQuirter (2024) pointed out that teacher education has a unique three-level transmission logic: AI ability of teacher educators → AI ability of pre-service teachers → AI literacy of K-12 students, and educational internship is the key node connecting the second and third levels.

The study by Yadav et al. (2025) provides a micro-level practical approach: pre-service teachers first independently complete lesson plans in instructional design tasks, then use AI to generate lesson plans on the same topic, and then compare the differences between the two, critically modify the AI lesson plans and explain the reasons.

3.4. Value Orientation: Cultivating Teaching Innovation Ability under AI Integration

The integration of AI-generated tools not only adds another type of teaching tool, but also promotes the intrinsic upgrading of teaching innovation capabilities, which is specifically reflected in three core dimensions.

3.4.1. Instructional Design Innovation: From Standardization to Personalization

Traditional instructional design often employs standardized, uniform schemes, making it difficult to consider individual student differences. AI-generated tools, on the other hand, provide technical support for personalized and differentiated instructional design. Gulen and Kucuk (2026) found that, after systematic training, pre-service teachers are able to use AI tools to design multimodal and more interactive teaching materials, significantly improving the richness and innovation of their instructional plans.

However, it is important to emphasize that the core of innovative instructional design is not how much content AI generates, but rather how teachers select, modify, and reorganize AI content based on teaching objectives. This proposition is consistent with the TPACK framework’s emphasis on pedagogical reasoning as the mediating factor between technology and content, and is empirically illustrated by the case study of Yadav et al. (2025), which shows that only when pre-service teachers possess solid subject teaching knowledge can they integrate fragmented AI-generated content into innovative solutions that conform to teaching principles and are tailored to students’ learning situations. It should be noted that this claim currently rests primarily on qualitative case evidence; further quantitative validation across diverse subject domains is needed before it can be generalized.

3.4.2. Innovation in Evaluation Methods: From Outcome-Oriented to Process-Oriented

AI tools have had a significant impact on traditional assessment systems, forcing pre-service teachers to innovate their assessment concepts and methods. Estaiteyeh and McQuirter (2024) pointed out that in the face of the academic integrity challenges brought by AI, simple prohibition and

detection are not long-term solutions. The real solution is to reconstruct the assessment system: shifting from paper-and-pencil tests and paper writing that focus on the final outcome to performance-based assessment, project-based assessment, and multimodal assessment that focus on the process (Kalniņa et al., 2024; Yadav et al., 2025).

3.4.3. Innovation in Ethical Thinking: From Technological Worship to Rational Prudence

Teaching innovation cannot cross the bottom line of educational ethics; therefore, ethical judgment is an important component of teaching innovation capabilities. Ethical thinking innovation in the AI era requires pre-service teachers to shift from passively complying with rules to proactively anticipating risks and avoiding harm. Hsu (2026) systematically outlined seven ethical dimensions of AI educational applications: bias and reliability, privacy and data protection, transparency and disclosure, accountability and professional judgment, academic integrity and assessment validity, fairness and subjectivity, and environmental sustainability.

The study by Gulen&Kucuk (2026) confirms that after systematic ethical training, pre-service teachers will proactively incorporate factors such as privacy protection and data security into their decision-making criteria when selecting AI tools and designing teaching activities, demonstrating a more mature and prudent innovative thinking.

4. Discussion

4.1. Core consensus of existing research

An integrative review of the included studies indicates that the reviewed literature generally converges on three core issues, although the evidence base remains limited and geographically skewed.

First, the reviewed studies consistently frame the integration of AI-generated tools into pre-service teacher education as a necessary and accelerating trend, and identify the core of training as “competency + ability” rather than simply technical operation (Tenberga & Daniela, 2024).

Second, the available evidence suggests that effective AI integration should adhere to the principles of tiered and progressive learning and individualized instruction; pre-service teachers with different backgrounds and developmental stages show significantly different needs.

Third, the reviewed studies collectively support the view that AI education should be integrated throughout the teacher training process, creating a closed loop of curriculum, practice, and reflection (Blonder et al., 2025).

4.2. Differences and Controversies in Existing Research

Due to differences in research location, research subjects, and research perspectives, existing

studies also exhibit some significant differences and controversies.

First, there are significant differences in the AI awareness and application levels of pre-service teachers across different regions. These differences are related to both the level of digital infrastructure in each region and the local education policy orientation.

Secondly, there is controversy regarding the role of AI in teaching. Some studies emphasize AI's role as a "burden-reducing tool," arguing that its core value lies in replacing repetitive tasks and improving teaching efficiency; others emphasize AI's role as a "cognitive partner," believing its core value lies in stimulating teachers' creative thinking and expanding the boundaries of teaching possibilities. This controversy essentially stems from a disagreement on the value proposition of educational technology: is technology a tool for improving efficiency, or a variable that reshapes education? (Eşki & Eryılmaz, 2026)

Third, there is no consensus yet on the boundaries and scale of AI integration; it is still in the exploratory stage, and different educators and schools have drastically different answers. (Ning, Zhang, Xu, Zhou, & Wijaya, 2024)

4.3. Profound Implications for Cultivating Teaching Innovation Ability

AI-generated tools provide unprecedented technological conditions for teaching innovation, but the fundamental driving force for teaching innovation will always be teachers' educational philosophy and professional competence.

Therefore, cultivating pre-service teachers' innovative teaching abilities must adhere to the principle of "education as the foundation and technology as the tool": we must not deviate from the essence of education in pursuit of technological trends, but rather be guided by real teaching problems, allowing AI tools to serve better educational outcomes. At the same time, we must be particularly wary of the misconception of "technology as omnipotent," cultivating pre-service teachers' critical thinking and professional autonomy, ensuring they always act as masters of technology rather than followers.

Furthermore, from a sustainable development perspective, the integration of AI tools is not a one-off technical training but a long-term process of capability iteration. Pre-service teacher training should not only teach students how to use current AI tools but also cultivate their ability to continuously learn new technologies and adapt to new changes, enabling them to keep up with technological developments and continuously innovate in teaching throughout their future careers.

4.4. Implications for the Chinese Context

The foregoing synthesis draws primarily on empirical studies conducted in Western and European contexts, which limits the direct transferability of findings to China's pre-service teacher education system. Nevertheless, several policy initiatives in China provide a supportive infrastructure for the integration pathways identified above. In 2018, the Ministry of Education issued the AI Innovation

Action Plan for Institutions of Higher Education, calling for the deep integration of AI and higher education and the cultivation of AI-competent talent. Subsequently, the MOE promulgated the Teacher Digital Literacy Standard in 2022, defining five dimensions—digital awareness, digital technology knowledge and skills, digital application, digital social responsibility, and professional development—comprising 33 indicators. Most recently, in 2025, the MOE launched the Digital Empowerment for Teacher Development Initiative, which explicitly includes a "Teacher Digital Literacy Enhancement Action" and calls on normal universities to establish smart education centers to support pre-service teachers' AI-integrated teaching competencies.

These policy developments align with the tiered, progressive competency model proposed in this review. However, empirical research on Chinese pre-service teachers' AI literacy remains scarce in international journals, and most existing Chinese-language studies focus on digital literacy broadly rather than generative AI specifically. Future research should prioritize empirical investigations of AI integration in Chinese normal university curricula and educational internships to contextualize the global findings reviewed here.

5. Conclusion

This study, through a systematic review of relevant literature, comprehensively presents the research status and practical approaches of integrating AI-generated tools with the cultivation of teaching innovation capabilities in pre-service teacher training, and mainly draws the following conclusions:

First, at the conceptual and theoretical level, the academic community has formed a hierarchical conceptual system of "AI literacy - AI ability - teaching innovation ability" and established authoritative capability frameworks such as UNESCO and EU-OECD, providing standardized references for training practices.

Second, regarding the current situation and problems, the global pre-service teacher community generally holds a cautiously optimistic attitude towards AI-generated tools, but there are common problems such as low application level, insufficient teaching transformation, and weak ethics and critical thinking. The gap between theoretical understanding and practical application is the core bottleneck restricting the development of pre-service teachers' AI capabilities.

Third, at the level of integration pathways, the academic community has explored three effective models: curriculum-based embedding to achieve systematic capacity building, workshops and scenario-based interventions to achieve short-term, specialized breakthroughs, and practical field penetration to achieve real-world capacity transformation.

Fourth, in terms of capability dimensions, teaching innovation capability in the AI era includes three core dimensions: instructional design innovation, assessment method innovation, and ethical

thinking innovation. These three dimensions correspond to the teaching process, outcome, and bottom line, respectively, and together constitute a complete innovation capability structure.

Based on the above conclusions, in order to optimize China's pre-service teacher training system and promote the deep integration of AI-generated tools and the effective improvement of teaching innovation capabilities, the following practical suggestions are proposed:

Construct a tiered and progressive AI literacy development system. It is recommended to integrate AI education content throughout the entire pre-service teacher training process, setting three levels of training objectives: lower grades focus on basic AI awareness and ethical literacy, helping students build a rational understanding of AI; middle grades focus on the teaching application of AI tools, integrating AI-assisted lesson preparation and resource creation skills into subject courses; upper grades, combined with teaching internships, focus on AI-integrated instructional design and assessment innovation, achieving a gradual progression of abilities.

We promote a closed-loop training model of "theory-practice-reflection". In terms of teaching methods, we integrate lecture, critical inquiry and co-design methods; in terms of teaching process, we establish a complete closed loop of "classroom learning-simulation exercises-internship practice-debriefing and reflection".

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